Probing Gluon Saturation through Dihadron correlations at an Electron-Ion Collider

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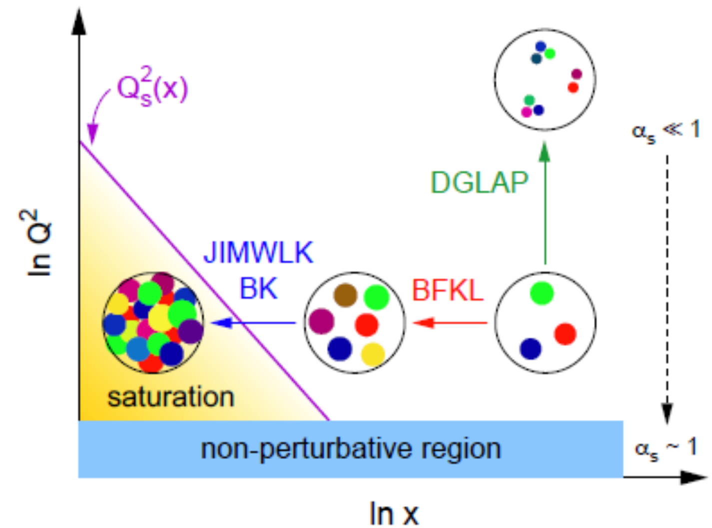
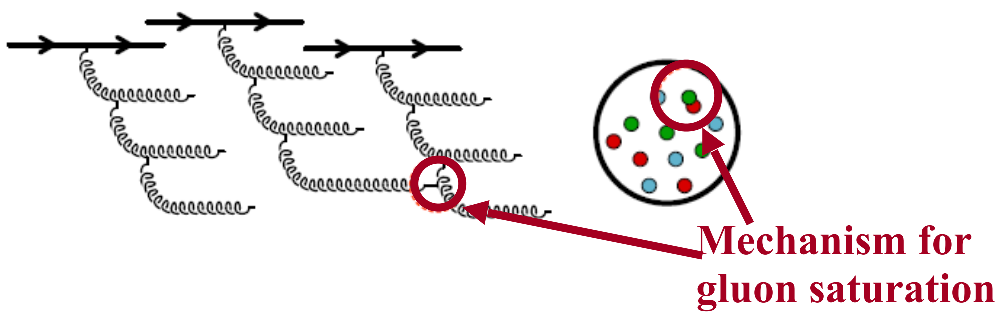
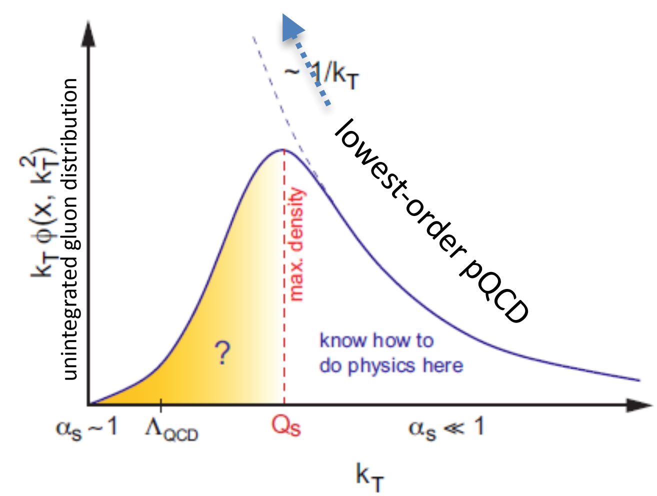
exploring gluon saturation regime

- Gluons dominate at small-x regime
  - 99% of proton mass accounted by QCD interaction
  - Gluon PDF grows explosively at small x
- Nonlinear evolution like BK evolution alternative to DGLAP, BFKL due to gluon recombination
- Saturation regime: $Q^2 < Q^2_s(x)$

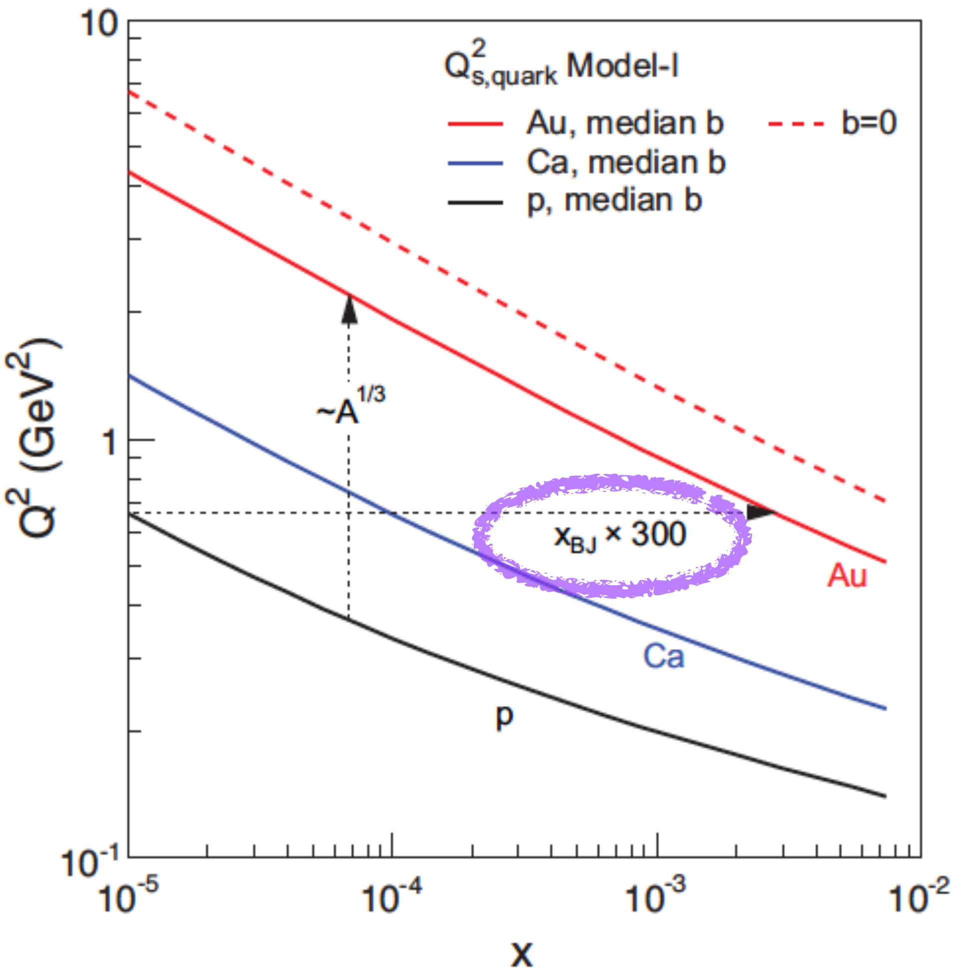


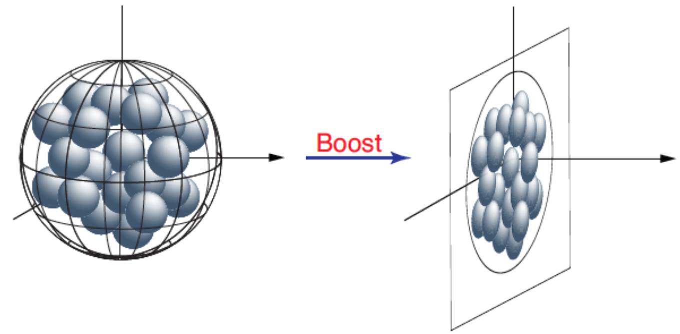




gluon transverse momentum

nuclear amplification of saturation



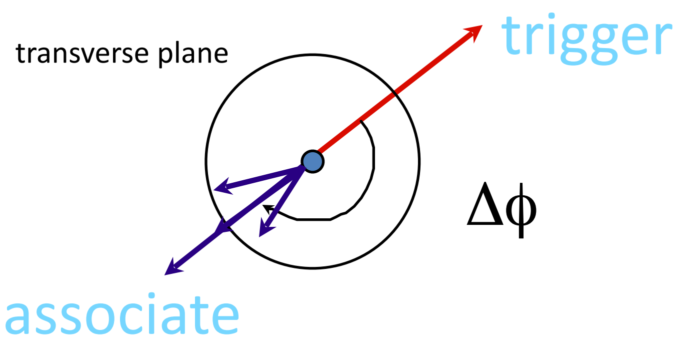


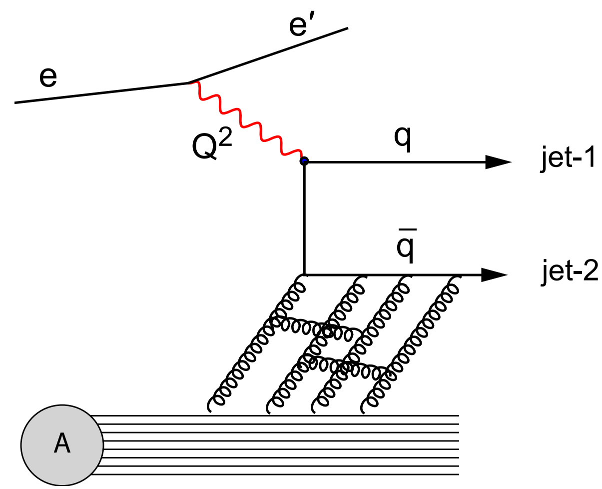
- Transverse gluon density scales with nuclear size at high energy/small-x
  ⇒ Effective x much smaller in large nuclei

$$Q_S^2(x, A) \sim Q_0^2 A^{1/3} \left(\frac{x_0}{x}\right)^\lambda$$

Q_0=1 GeV, x_0=3x10^{-4},λ=0.288

saturation and dihadron correlation





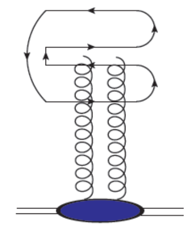
$$C(\Delta\phi) = \frac{N_{\text{pair}}(\Delta\phi)}{N_{\text{trig}}}$$

- Dijet/dihadron correlation sensitive to the transverse momentum imbalance
- In the saturation regime (< Qs), large transverse momentum imbalance for the hadron pairs expected, which leads to back-to-back jet/hadron pairs to de-correlation

dihadron correlation in saturation formalism

Correlation Function

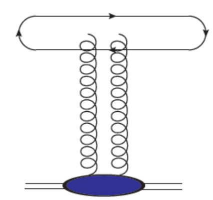
$$C(\Delta\phi) = \frac{1}{\frac{d\sigma_{\text{SIDIS}}^{\gamma^*+A\to h_1+X}}{dz_{h1}}} \frac{d\sigma_{\text{tot}}^{\gamma^*+A\to h_1+h_2+X}}{dz_{h1}dz_{h2}d\Delta\phi}$$



Pair cross-section (Weizsäcker-Williams gluon distribution $G^{(1)}$)

$$\frac{d\sigma_{\text{tot}}^{\gamma^*+A\to h_1+h_2+X}}{dz_{h1}dz_{h2}d^2p_{h1\perp}d^2p_{h2\perp}} \sim xG^{(1)}(x_g, q_\perp) \sim \mathcal{F}(x_g,q_\perp) = \frac{1}{2\pi^2}\int d^2r_\perp e^{-iq_\perp r_\perp}\frac{1}{r_\perp^2}\left[1-\exp\left(-\frac{1}{4}r_\perp^2 Q_s^2\right)\right]$$

gauge link for large nucleus for small-x using McLerran-Venugopalan model



Trigger particle cross-section (color dipole gluon distribution $G^{(2)}$)

$$\frac{d\sigma_{\text{SIDIS}}^{\gamma^*+A\to h_1+X}}{dz_{h1}d^2p_{h1\perp}} \sim xG^{(2)}(x_g, q_\perp) \sim F_{x_g}(q_\perp) = \int \frac{d^2r}{2\pi^2} e^{iq_\perp \cdot r_\perp}\frac{1}{N_c}\text{Tr}\langle U(r_\perp)U^\dagger(0)\rangle_\rho$$

$$\simeq \frac{1}{\pi Q_{sA}^2}\exp\left[-\frac{q_\perp^2}{Q_{sA}^2}\right].$$

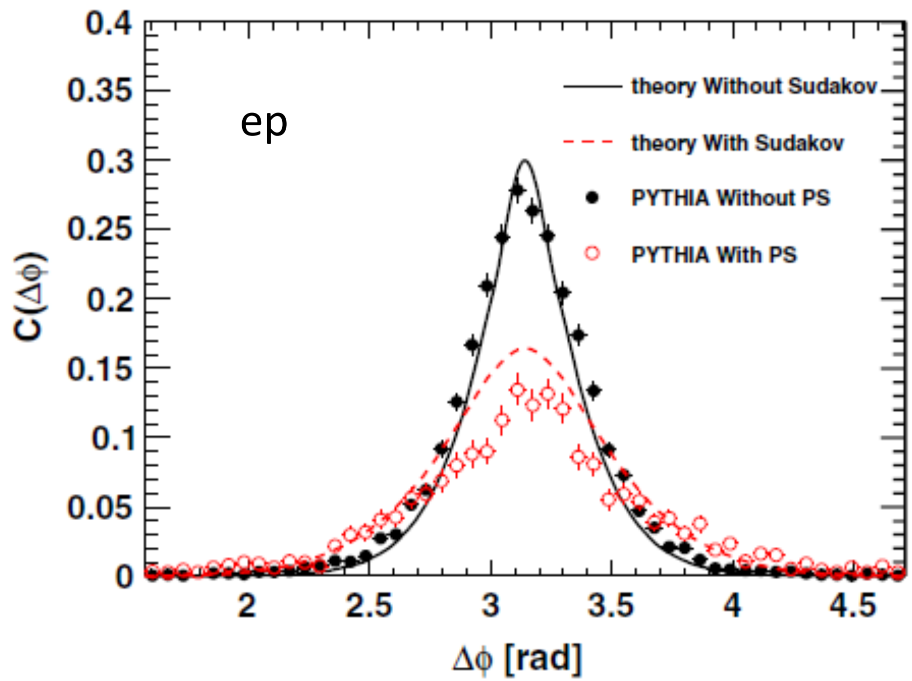
Fourier transformation of dipole cross-section

parton shower in dihadron correlation
- Sudakov effect in nuclei

$$\mathcal{F}(x_g, q_\perp) = \frac{1}{2\pi^2}\int d^2 r_\perp e^{-iq_\perp r_\perp}\frac{1}{r_\perp^2}\left[1-\exp\left(-\frac{1}{4}r_\perp^2 Q_s^2\right)\right]$$
$$\times\exp\left[-\frac{\alpha_s N_c}{4\pi}\ln^2\frac{K^2 r_\perp^2}{c_0^2}\right]$$

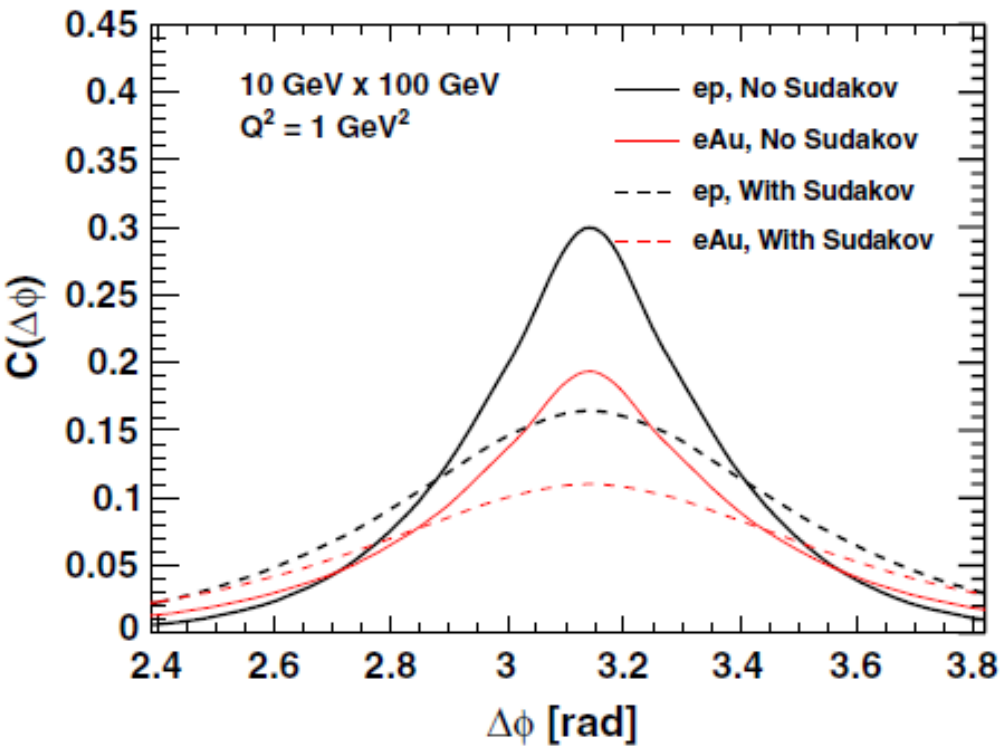
$K^2 = P_T^2$ or $K^2 = Q^2$, $C_0=2e^{-\gamma_E}$

- Nuclear Beyond leading order calculation is achieved by inclusion of Sudakov factor at leading double log level in WW gluon distribution ($O(Q^2)\sim O(P_T^2)$)
- Parton shower effect is effectively cast into Sudakov factor in saturation calculation for dihadron correlation



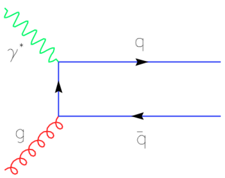
saturation formalism with Sudakov factor

- Strong suppression expected at away-side of the correlation function
- Away-side suppression is due to a combination of Sudakov factor and saturation effects
- Nuclear modification of parton shower at leading order is small in the saturation formalism

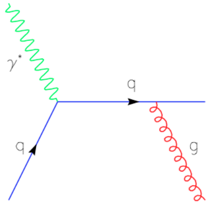


Parton shower in nuclei not well known: Study to distinguish the contribution from Sudakov and saturation can be achieved by running with different target types and/or utilizing the near side peak scanned with different Q^2

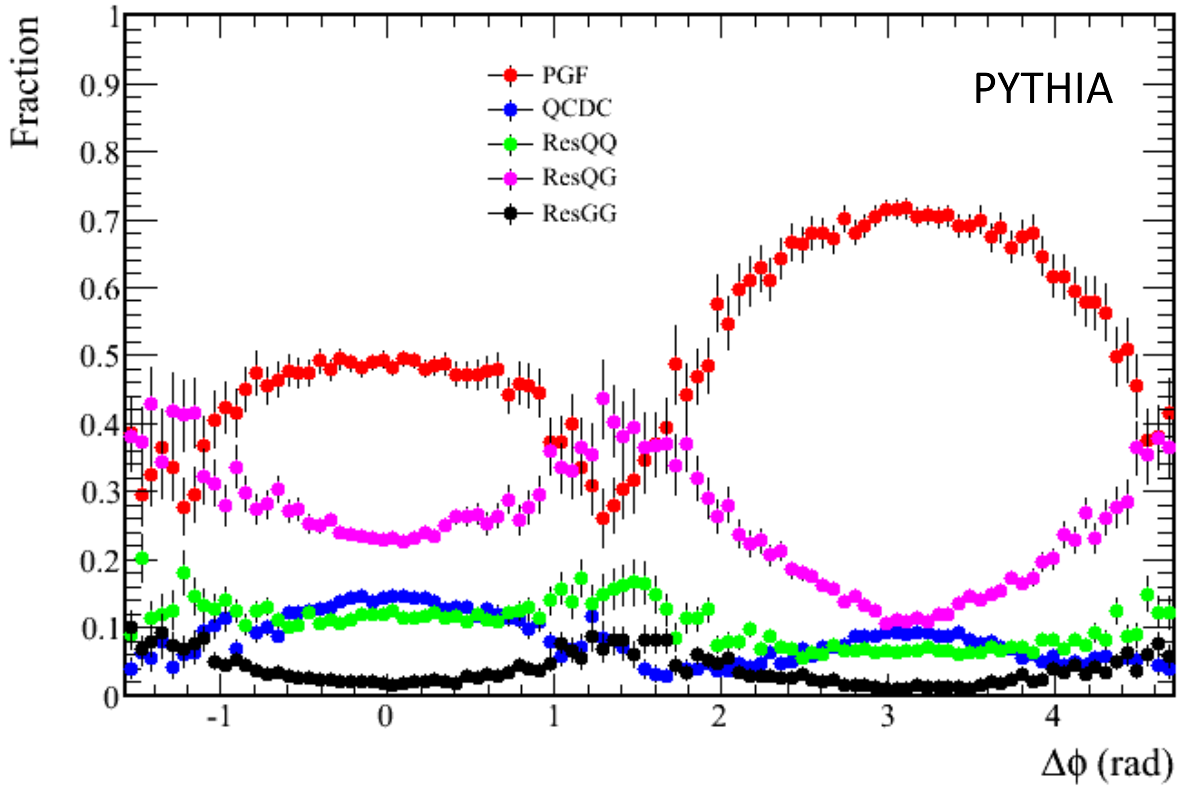
QCD processes contributing to back-to-back dihadron in DIS at EIC energies



PGF



QCDC



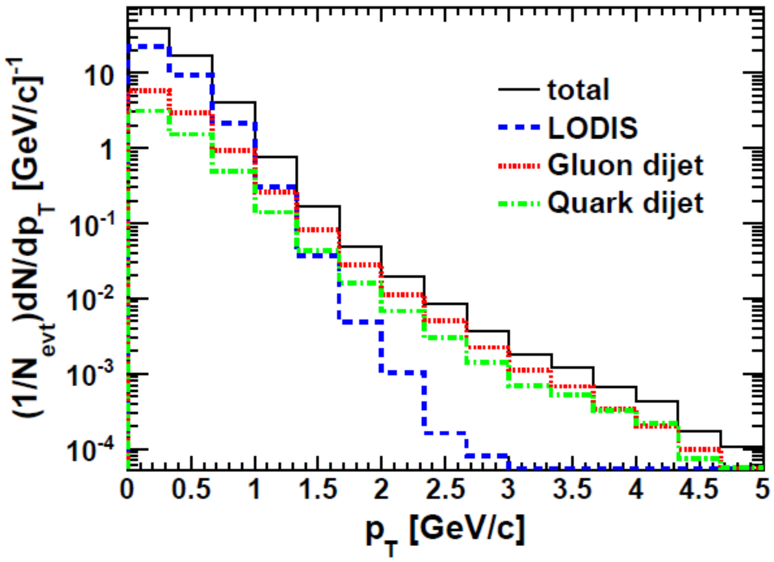
- Photon-Gluon Fusion dominates (~70%) away-side correlation
- Processes without gluon coupling < ~20%

Particle yield from different underlying process

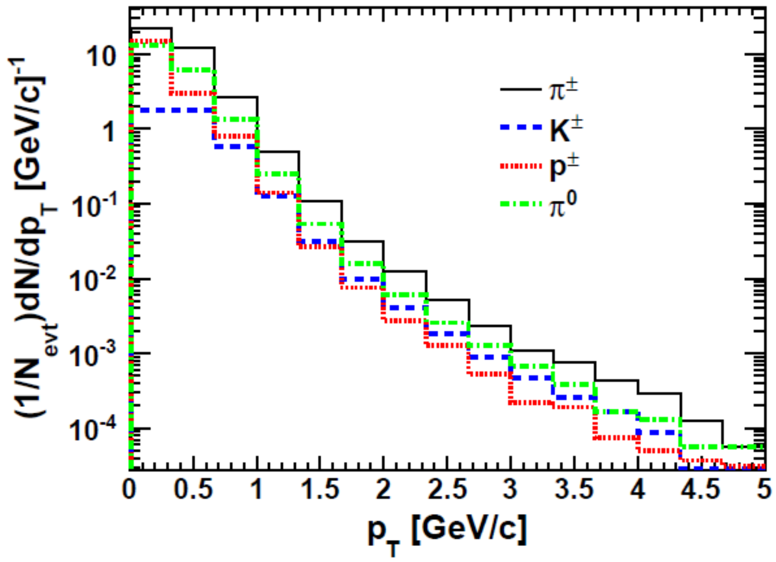
e+p 10 GeV x 100 GeV
$1<Q^2<20\ GeV^2$
$0.01<y<0.95$

- High-p_T particles generated mainly from gluon/quark dijet process
- Pions make up of the major part of the produced final state particles

Charged particle production



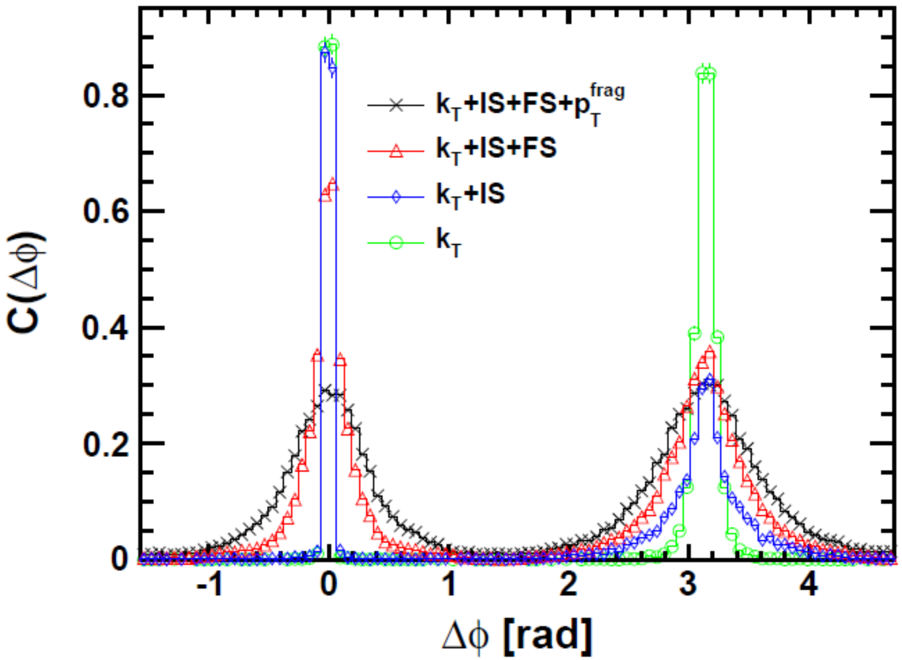
Particle production in all process



impact on dihadron correlation function from different QCD effects

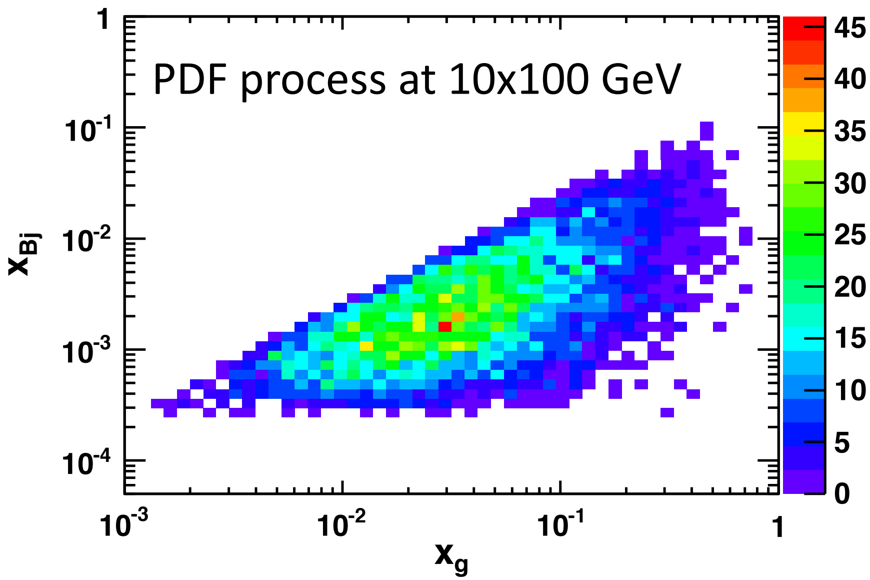
- Near-side peak width mainly affected by final state parton shower and fragmentation

- Away-side peak width dominated by initial state parton shower

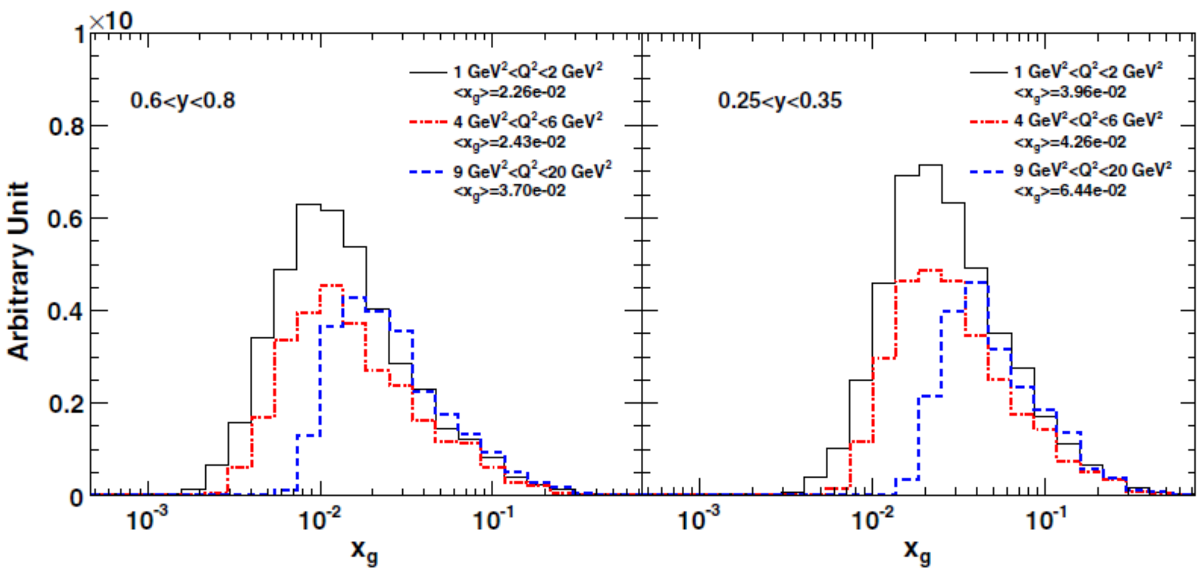


	Near-side $\Delta\phi$ RMS	Away-side $\Delta\phi$ RMS
k_T	0.21	0.25
$k_T + \text{IS}$	0.30	0.72
$k_T + \text{IS} + \text{FS}$	0.65	0.81
$k_T + \text{IS} + \text{FS} + p_T^{\text{frag}}$	1.00	1.00

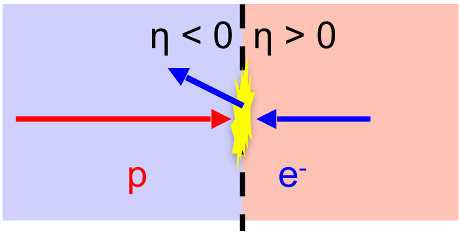
kinematics access



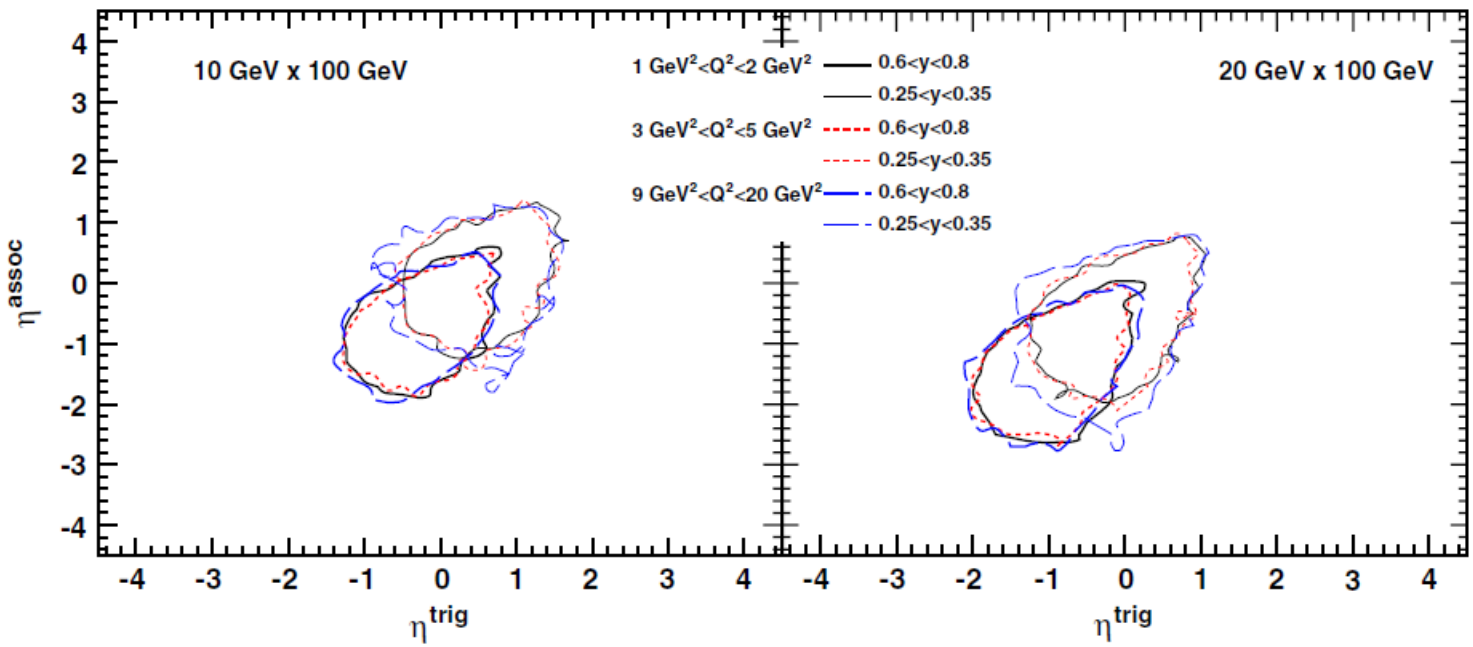
- x_g coverage can be constrained by selecting certain kinematics bins
- EIC accessible kinematics region covers the transition to saturation regime



experimental measurements of dihadron correlations at EIC



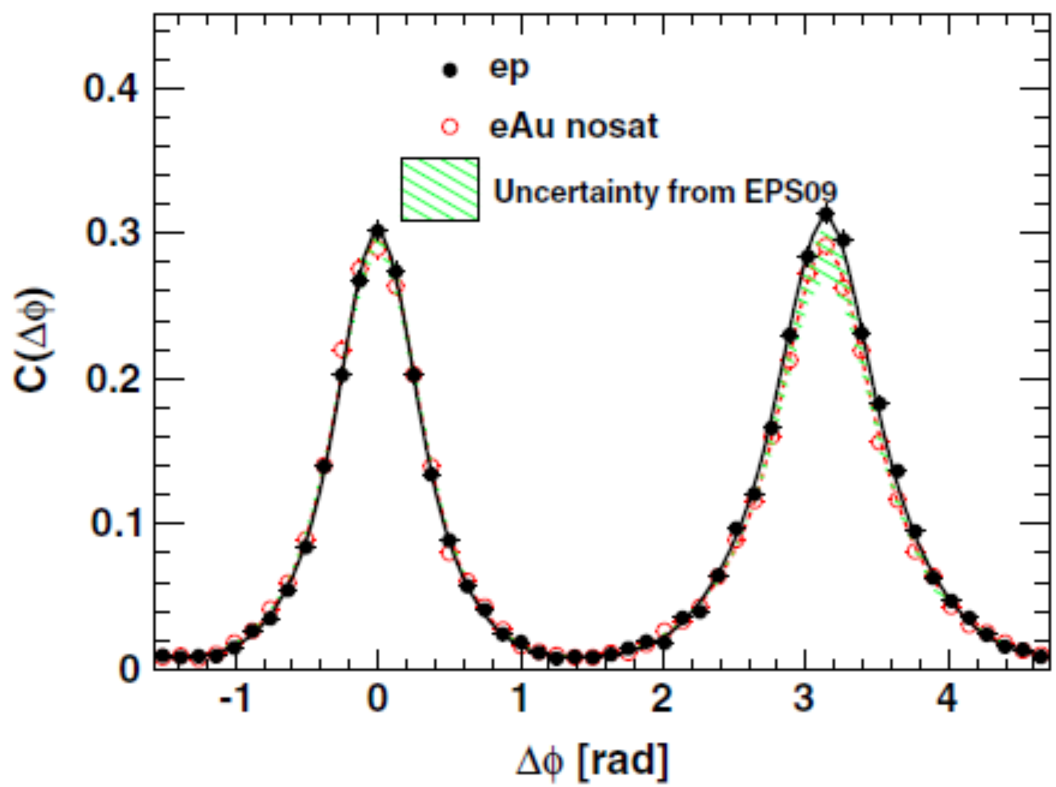
Device	acceptance	smearing
Barrel track	*-1<η<1*	*0.1%*p*
Endcap track	*1<|η|<2*	*1%*p*
Endcap Cal	*-4.5<η<-2*	*1.78% * sqrt(E) + 0.69% * E*



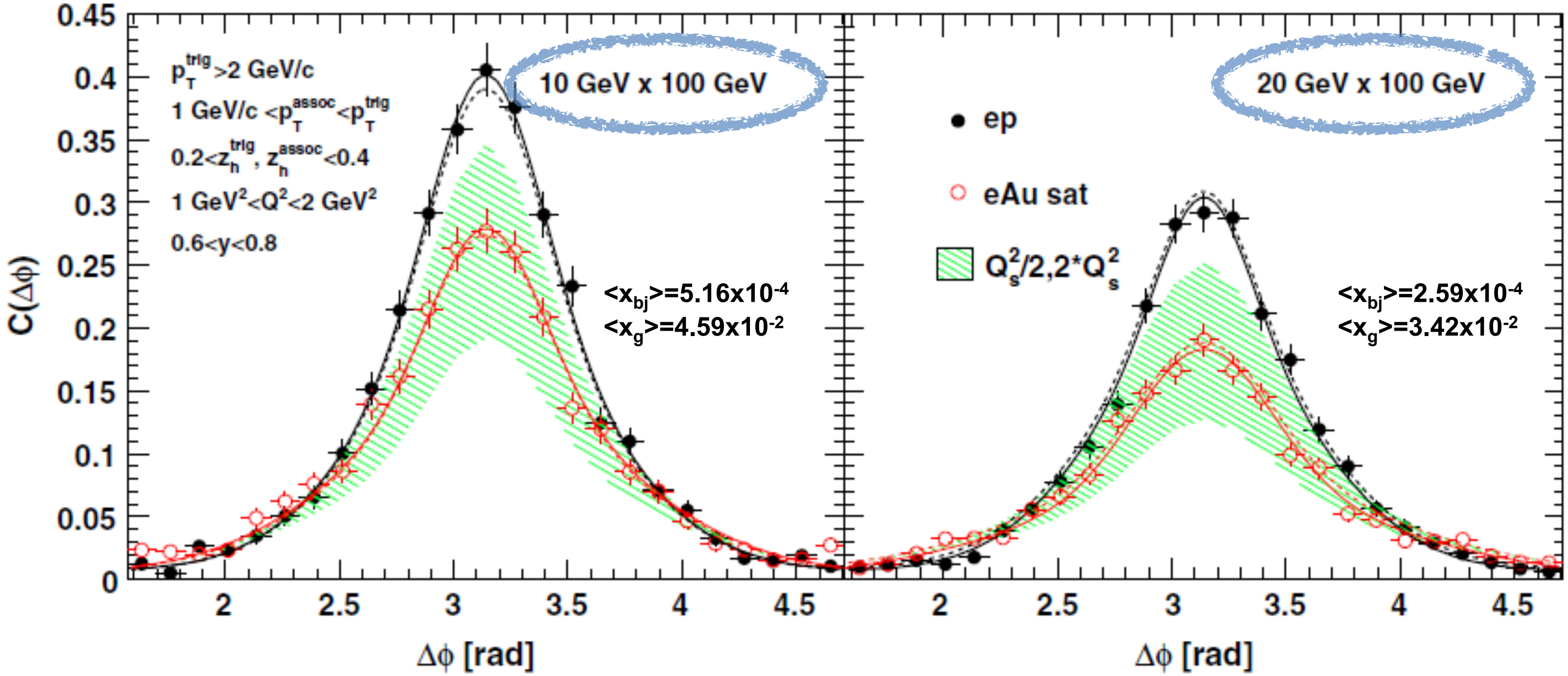
dihadron correlation with non-saturation prediction

ep/eAu 20x100 GeV
Cuts:
$0.6<y<0.8$
$1 <Q^2<2$ GeV^2
$p_{t1}>2$ GeV, 1 GeV$<p_{t2}<p_{t1}$
$0.2<z1,z2<0.4$
$2560 < \nu < 3400$ GeV
$<x_{bj}>=2.59\times10^{-4}$
$<x_g>=3.42\times10^{-2}$
Charged particles

Nuclear effects:
- nPDF EPS09
- Cold nuclear medium energy loss



saturation prediction and expected measurement at EIC



- EIC expected data from 1 fb^{-1} integrated luminosity at 10,20(e)x100(p/Au) GeV
- Saturation / no-saturation can be clearly distinguished
- Strong suppression cannot be reproduced by the non-saturation model

summary

- Dihadrons (Dijet) in DIS ep, eA provide gluon distributions.
- Nuclear dependent QCD effects and gluon saturation can be measured in dihadron correlations at an EIC over a broad kinematic range.
- The onset of the projected saturation region is well covered by the EIC energy regime and the proposed luminosity and the detectors are suitable to measure the gluon saturation with high precision through dihadron correlations.

Backup

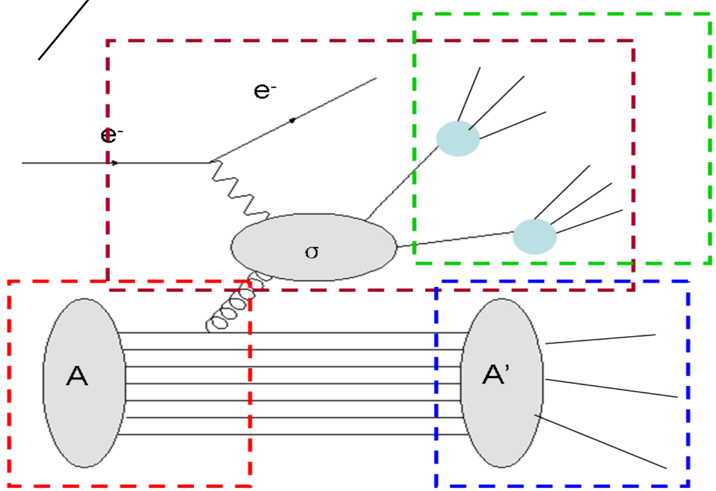
Monte-Carlo simulation for dihadron correlation in ep/eA

A hybrid model consisting of DPMJet and PYTHIA with nPDF EPS09.

- Nuclear geometry → DPMJET
- Nuclear PDF → EPS09
- Parton level interaction, parton shower and jet fragmentation → PYTHIA
- Energy loss effect for cold nuclear medium → Energy loss module by Salgado&Wiedeman
- Nuclear remnant evaporation → DPMJET

Decorrelation of dihadron:

- Higher order effects (parton shower)
- Noncollinear effects (intrinsic k_T)
- Fragmentation process (Jetset)



A non Saturation model

Connections to pA

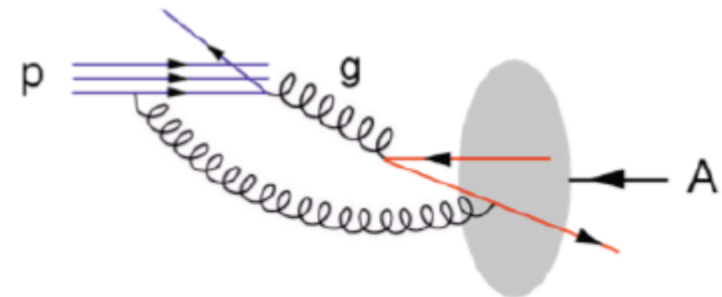
– Control initial/final state

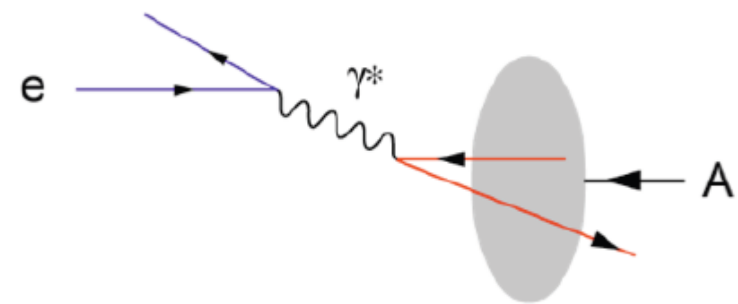
– eA experimentally much cleaner, no pedestal

  - no "spectator" background to subtract

– Access to the exact kinematics of the DIS process (x, Q^2)

– Constrain WW gluon distribution which is rarely known from other measurements





	DIS and DY	SIDIS	hadron in pA	photon-jet in pA	Dijet in DIS	Dijet in pA
$G^{(1)}$ (WW)	×	×	×	×	√	√
$G^{(2)}$ (dipole)	√	√	√	√	×	√